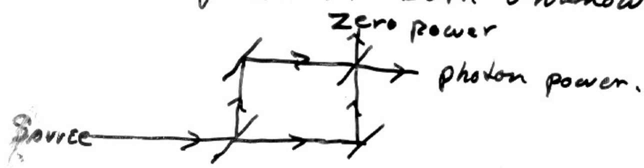
3.

Heterodyne Detection

Uncertainty principle requires $\Delta\phi \Delta n \geq 1/2$

or, for $\Delta n = \sqrt{n}$, $\Delta\phi \geq \frac{1}{2\sqrt{n}}$

This is true for absolute phase, not for relative phase of two waves, with absolute phase of both unknown. e.g. interferometer



"Squeezing"

Heterodyne detection

Current $i \propto (E_{LO} + E_s + E_0)^2$

$$\approx E_{LO}^2 + 2E_{LO}E_s + 2E_{LO}E_0$$

where E_{LO} = field of local oscillator

E_s = " " signal

E_0 = zero point fluctuation field

Power $\propto E_{LO}^2 (E_s^2 + E_0^2)$

where usually $E_0^2 \gg E_s^2$ and it produces 1 photon/sec/unit bandwidth

$\therefore$ Noise power $= 2h\nu\,\Delta\nu$ for two sidebands of width $\Delta\nu$.

Figure 4.3: Noise power in heterodyne detection associated with the uncertainty principle, assuming no special procedures such as "squeezing" are used.

4.

For signal power P_ν per unit bandwidth

heterodyne $$S/N = \frac{P_\nu}{h\nu}\sqrt{2\Delta\nu t}$$

where t is time length of measurement in seconds.

$\therefore$ Fundamental laws give S/N advantage to direct detection of $$\sqrt{\frac{e^{h\nu/kT}-1}{\varepsilon}}$$

if $$\frac{e^{h\nu/kT}-1}{\varepsilon} > 1$$

Table

λ	$\sqrt{e^{\frac{h\nu}{kT}}-1}$ for $T = 283^\circ K$
1 cm	0.071
100 μm	0.81
11 μm	10
3 μm	4.8×10^{3}
0.6 μm	2.6×10^{18}

Figure 4.4: Signal-to-noise ratios for ideal heterodyne detection and a numerical comparison with direct detection as a function of wavelength.

5.

Practicalities

Band width
- pros and cons
- factor of $\sqrt{\frac{100}{1/4}}$
- For $100\ cm^{-1}$ bandwidth, $\Delta T < 10^{-6}\ {}^\circ K$ for direct detection sensitivity
- Spectral problems

Non fundamental noise
- Leakage radiation — telescope noise
- " current in detectors

L.O. scattering and cure

Present limits for direct detection at $10\ \mu m$

For 1 sec ave.

limit $\sim 2 \times 10^{-15}$ watts. for minimum $\Delta\nu$
$= $ theoretical value for $\Delta\nu \approx 100\ cm^{-1}$

for $\Delta\nu$ actually $= 100\ cm^{-1}$, limit $\sim 5 \times 10^{-14}$ W.
" " $= 10\ cm^{-1}$, " $\sim 1.3 \times 10^{-14}$ W

Other direct vs. heterodyne differences
- Isolation of plane waves or point sources by heterodyne detection
- Isolation of fringe signal
- Decrease vs. no decrease of signal with multiple telescapes
- Difference in practical averaging time
- Complexities of each.

Figure 4.5: Various practical considerations which affect the relative performance of direct and heterodyne detection.

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